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AUTHOR McCloskey, Michael; And Others
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ABSTRACT

Through everyday experience people acquire knowledge about how moving objects behave. For example, if a rock is thrown up into the air, it will fall back to earth. Research has shown that people's ideas about why moving objects behave as they do are often quite inconsistent with the principles of classical mechanics. In fact, many people hold a systematic, well-developed naive theory of motion that bears a striking resemblance to a theory of mechanics popular in the 14th through 16th centuries. When a simple problem (focusing on the straight-down belief) was given to 80 college students, less than half reported the correct answer. The straight-down belief (or misconception) holds that when an object carried by another moving object is dropped, it will fall straight to the ground. One explanation is that this belief results from a visual illusion occurring in many common situations where carried objects, namely, the phenomenon of induced motion. Results of several experiments indicate that the type of induced motion effects suggested may be the source of the straight-down belief.
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The Straight-Down Belief

Michael McCloskey

Deborah Kohl

Allyson Washburn

Department of Psychology

Johns Hopkins University

Baltimore, Maryland 21218

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Through everyday experience people acquire knowledge about how moving objects behave. For example, everyone knows from experience that if a rock is thrown up into the air, it will fall back to earth.

For the past few years, I have been doing research aimed at determining what form people's knowledge about motion takes. This research has shown that people's ideas about why moving objects behave as they do are often quite inconsistent with the principles of classical mechanics. In fact, we have found that many people hold a systematic, well-developed naive theory of motion that bears a striking resemblance to a theory of mechanics popular in the fourteenth through sixteenth centuries.

Although people's ideas about why objects behave as they do are often incorrect, their ideas about how moving objects behave are usually not too far wrong. For example, most people have a pretty good idea of what sort of trajectory a ball thrown into the air will follow.

However, our research has uncovered a few strikingly incorrect beliefs about how objects in motion behave. These beliefs are particularly interesting, because it is not immediately obvious what sorts of experiences would lead to their development.

In this talk I want to discuss one very wrong belief about how moving objects act. I will first describe the belief. Then, I will suggest a possible explanation for how people come to develop the belief. Finally, I will present data consistent with this explanation.

Consider the simple pencil and paper problem shown in Figure 1. The problem shows a man walking on a level surface at a constant moderate speed. The man is holding a metal ball out from his side at shoulder height. The filled circle in the diagram represents the ball. When the man reaches the position shown in the diagram, he drops the ball. In other words, he simply releases the ball as he is walking along. After the man drops the ball, he continues walking,

at the same speed.

For this problem the subjects' first task is to indicate the point on the ground where the ball will hit after it is dropped. Next, the subjects are asked to draw the path the ball will follow as it falls from its original position in the diagram to the point on the ground where it will hit. Finally, they are asked to indicate about where the man will be at the instant the ball hits the ground.

The correct answer, as shown in Figure 2, is that the ball will fall forward in an arc. If we ignore air resistance, the man will be in the location indicated by the X at the instant the ball hits the ground. In other words, the ball will stay even with the man as it falls. If we take air resistance into account, the man will be slightly ahead of the ball.

The answer can be understood by realizing that the ball's motion may be analyzed into independent horizontal and vertical components. Before the ball is dropped it has a horizontal velocity equal to that of the man and a vertical velocity of zero. After the ball is released it acquires a constantly increasing vertical velocity due to the action of gravity. However, the ball's horizontal velocity remains constant after it is dropped (again ignoring air resistance). The result is a parabolic arc. Because the ball's horizontal velocity remains equal to that of the man, the ball will be even with the man when it hits the ground. (If we take air resistance into account the ball's horizontal velocity will decrease slightly as it falls, and the man will out-distance it slightly).

I recently gave this problem to about 80 college students. Some had never taken a physics course and others had completed one or more high school or college physics courses. Surprisingly, less than half of the subjects indicated that the ball would move forward as it fell. Forty-eight percent said that the

ball would fall straight down, as shown in Figure 3. Seven percent even said that the ball would fall backwards (see Figure 4).

These results do not seem to stem from some subjects misunderstanding the problem and thinking that they were supposed to depict the ball's motion with respect to the man. For one thing, the subjects were told first to indicate the point on the ground where the ball would hit. This instruction seems quite unambiguous. Second, all subjects who showed the ball falling straight down or backward indicated, as in Figures 3 and 4, that the man would be well ahead of the ball at the moment of impact. Finally, subjects' written explanations made it clear that they were indicating the ball's motion with respect to the ground.

The belief that an object carried by another moving object will fall straight down when dropped also shows up on other problems we have used. For example, in the problem shown in Figure 5 an airplane is flying along at a constant speed and a constant altitude. When the plane reaches the position shown in the diagram, a metal ball is dropped from the plane. The plane continues flying along at the same speed. Subjects are asked to draw the path the ball will follow as it falls to the ground, ignoring air resistance, and to indicate where the plane will be at the moment of impact.

The correct answer is shown in the upper left panel of Figure 6. The ball will fall in a parabolic arc, with the plane directly above the ball at impact. This problem was given to a group of Hopkins students who had not seen the problem in which the man dropped the ball. About half of the subjects indicated that the ball would move forward as it fell, either in an arc or in a straight diagonal line, as shown in the upper right panel. Thirty-five percent of the subjects indicated that the ball would fall straight down, as shown in the lower right panel and 10% thought that the ball would move backwards as it fell.

Other problems show similar results. It seems, then, that many people have the incorrect belief that when an object that is being carried by another moving object (like a person or an airplane) is dropped, it will fall straight to the ground. I will call this the straight-down belief.

The straight-down belief, by the way, fits very nicely into the naive theory of motion that many people hold. Unfortunately, I don't have time to elaborate this point here.

The issue I want to focus on is, what is the source of this strange idea that a carried object falls straight down when it is dropped? I want to suggest that the belief stems from a visual illusion occurring in many common situations where carried objects are dropped. Specifically, I am suggesting that in situations where a carried object is dropped, the dropped object may be perceived as falling straight down or even backwards.

The argument I want to make involves the phenomenon of induced motion. In a typical induced motion experiment the subjects sits in a completely dark room. The only visible objects are a luminous rectangle and a luminous spot inside the rectangle (see Figure 7). If the rectangle is moved to the left while the spot remains stationary, the subject will often see the spot as moving to the right. In this situation the motion of the rectangle is said to induce motion in the spot.

One interpretation of the induced motion phenomenon is that in situations involving an object visually surrounded by another object, the perceived absolute motion of the surrounded object will be determined entirely by its motion relative to the surrounding object. According to this view, because the spot in this situation is moving to the right relative to the rectangle, it is perceived as having an absolute motion to the right.

In many if not most everyday situations in which an object carried by

another moving object is dropped, the carrying object visually surrounds the carried object as it falls. For example, in the case of the man dropping the ball the man's body surrounds the ball as it falls. Similarly, for an object dropped from a moving car the car surrounds the falling object.

Thus, the carrying object may serve as a frame of reference for the carried object as it falls, such that the perceived absolute motion of the falling object is determined largely by its motion relative to the carrier. Because ignoring air resistance the dropped object will fall straight down relative to the carrier, the dropped object may be perceived as having an absolute straight down motion. In situations where air resistance effects are significant, the dropped object may move backward relative to the carrier and so may be perceived as falling backward. What I am suggesting then, is that the forward movement of the carrier may result in an induced horizontal motionlessness or even an induced backward motion of the dropped object.

To those who are familiar with the induced motion literature, this proposed explanation must seem implausible at best. Induced motion experiments are conducted in dark rooms in which only the surrounded and surrounding objects are visible. However, in everyday situations where carried objects are dropped, there are almost always other objects visible. It is well-known that induced motion phenomena are difficult if not impossible to obtain under these conditions. Further, an excellent recent paper by Irving Rock and his colleagues provides theoretical reasons for not expecting induced motion effects in everyday situations.

Fortunately, I didn't know all this when I first arrived at the induced motion explanation, and so I did an experiment to see if the explanation was reasonable. This experiment used a computer simulation of a situation in which a carried object is dropped. Figure 8 shows the basic arrangement. The large

rectangle represents the computer's display screen. The box with the horizontal and vertical lines through it represents the carrying object -- for example, a person walking -- and the filled circle represents the carried object -- for example, a ball.

The program first showed this situation. Then when a button was pressed, the box moved across the screen from left to right at a constant speed of about 8.5 deg/sec. The ball moved with the box for about 1/3 of the distance across the screen, and then it began to fall. The program was set up so that the ball could move in several different ways as it fell. For example, it could fall backward as shown in Figure 9. The horizontal line shows the ball's movement before it fell, and the vertical line moving backward shows the falling of the ball. The asterisk at the right shows the horizontal position of the box when the ball reaches the end of the path shown in the slide.

The ball could also fall straight down (Figure 10) or it could move forward as it fell, but not as far forward as the box (Figure 11). Or it could move forward, as in Figure 12, at the same speed as the box (this is of course what a dropped object would do in the absence of air resistance). Or the ball could even move further forward than the box as it fell.

In the experiment using this simulation each of 18 subjects viewed about 25 different motions of the ball. For each trial the subjects' task was to draw the path the ball followed; the path of the box did not have to be indicated.

The subjects were not told that the experiment had anything to do with falling objects. They were told simply that we wanted to see how accurately people could draw the path of a moving spot.

For each trial the subject was given an actual-size drawing of the computer screen on which to draw the path of the spot. The instructions made clear that the path was to be drawn relative to the screen and not relative to the box.

The falling motions illustrated in previous slides were mixed with trials involving various other sorts of motions. For example, the ball sometimes started at the bottom of the box and moved upward.

Also, for every trial involving the box there was a trial in which the motion of the ball was identical but in which no box was shown. In other words, only the ball was shown on these trials. The no-box trials were included so that the paths drawn by subjects on trials including the box could be compared not only to the actual trajectory of the ball, but also to the path drawn when no box was presented.

The experiment was done under normal office lighting. The border around the screen provided a clear stationary frame of reference surrounding the display. In fact, the entire computer console in which the screen was mounted was clearly visible.

If the induced motion explanation for the belief that carried objects fall straight down when dropped is correct, then on trials involving the box subjects should misperceive the horizontal motion of the ball. For example, they might perceive the ball as falling straight down on some trials where it actually falls forward, and as falling backward when it actually falls straight down.

The results were quite clear. The box had a dramatic effect on the perceived motion of the ball. Figure 13, for example, shows results for a trial in which the ball fell forward, but not quite as far as the box. The dotted line shows the actual path of the ball, and the asterisk indicates the position of the box at the moment the ball reached the end of the path. The line labelled "no box" indicates the average of the paths drawn by the subjects when the box was not present, and the line labelled "box" indicates the average path drawn on trials when the box was present. In other words, when the box was present, the ball was perceived as moving backward even though it actually moved forward.

Figure 14 shows the results for the situation in which the ball stayed with the box as it fell (the situation depicting the actual behavior of a ball dropped in the absence of air resistance.) In the presence of the box the average path was only slightly forward, and in fact 8 of the 18 subjects drew straight-down paths for this stimulus and 1 subject indicated that the ball would move backward.

These results clearly show that the type of induced motion effects I have suggested may be the source of the straight-down belief occur when people view a simulation of everyday situations where carried objects are dropped. If anything, these effects should be less likely to occur in the simulated situation than in the real world, because in the simulation the border around the screen provided a clear stationary frame of reference immediately surrounding the moving objects. Therefore, it seems reasonable to conclude tentatively that in everyday situations where carried objects are dropped, the objects may be perceived as falling straight down or even backwards (in situations where air resistance is a significant factor).

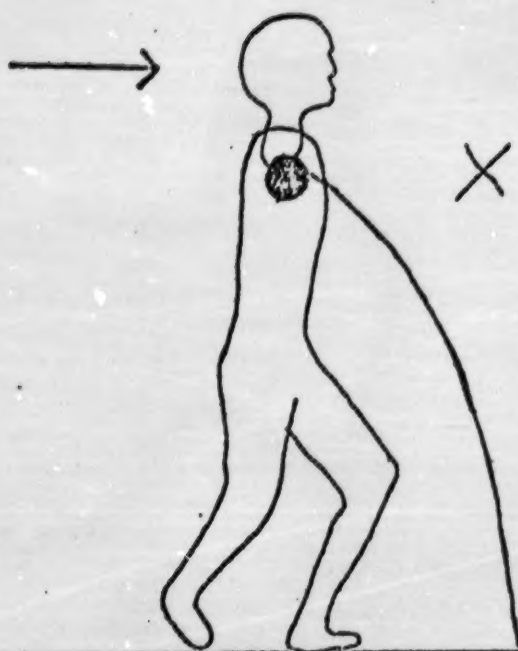
This conclusion does not necessarily imply that the straight down belief results directly from an induced motion illusion occurring in everyday situations where carried objects are dropped. However, this is certainly a plausible explanation.



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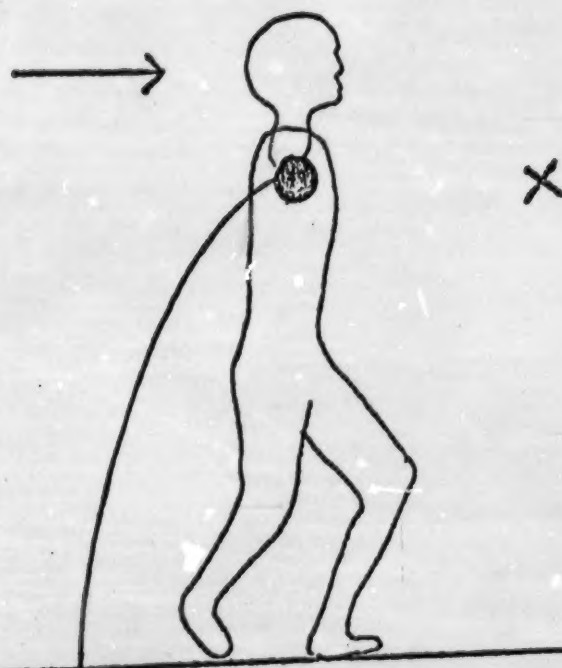
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GROUND

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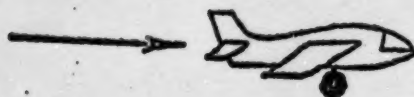
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GROUND

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GROUND



A



B



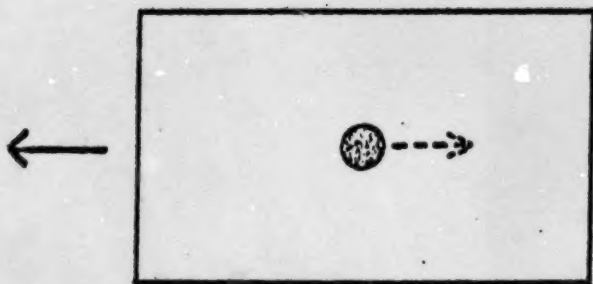
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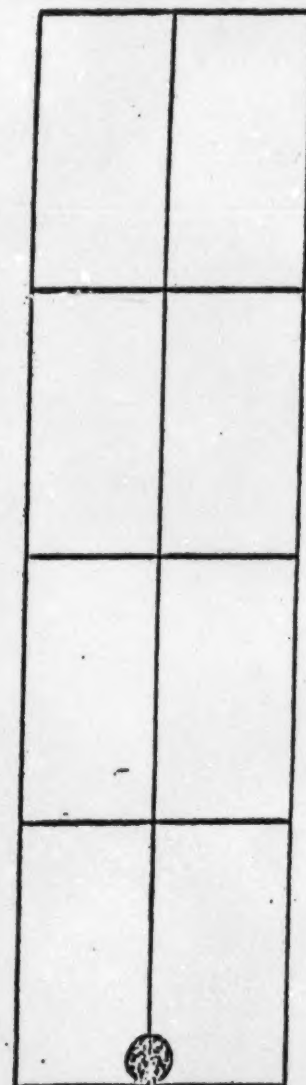


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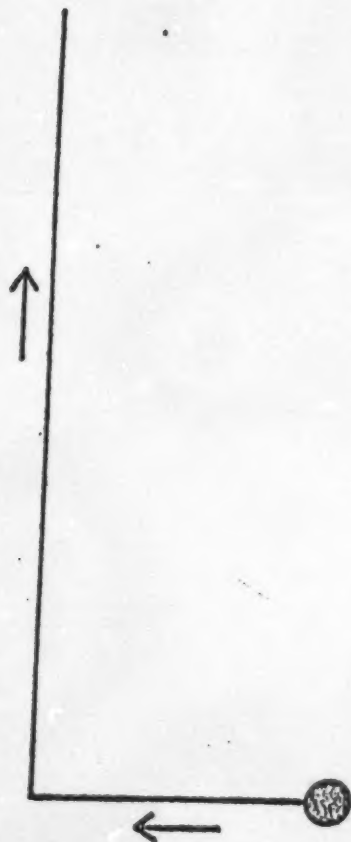


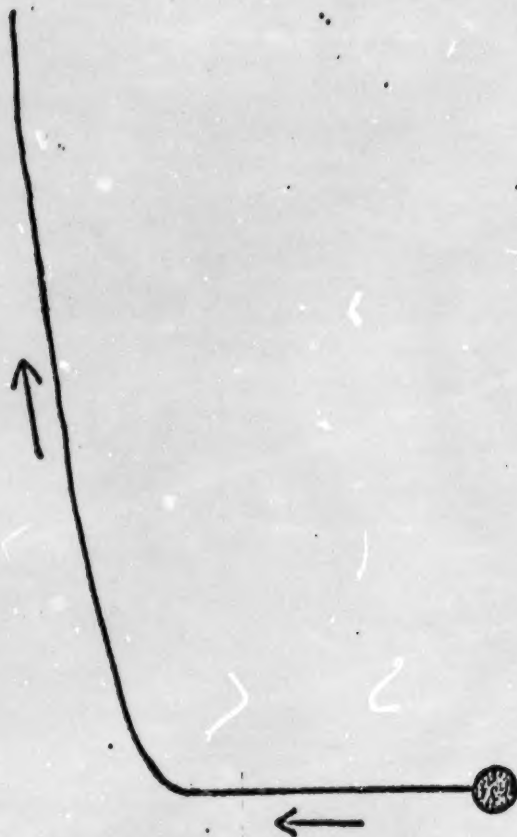
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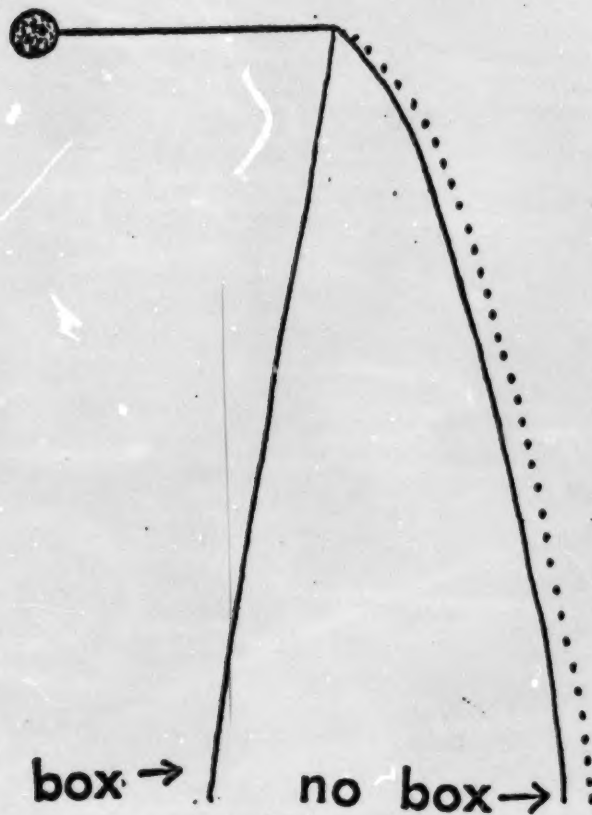
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